three or four adults of each kind should be thus transmitted, to supply our collection with skeleton and stuffed specimens, in addition to at least one to be retained entire in spirit. The *micro-mammalia*, as they have been designated (as Bats, Shrews, Mice, &c.), require to be thus amply represented in museums, for their specific distinctions to be rightly understood in many cases; and the chaos of Indian Muridæ, in particular, will be never reduced to systematic order, with the synonyms correctly adjusted, until such a tolerably complete collection of them from all quarters has been brought together.

[The notes appended to the present memoir were most of them taken from specimens in the British and India-House Museums, at the request of Mr. Blyth, and kindly permitted by Dr. Gray and Dr. Horsfield; but having reached Calcutta too late for insertion, Mr. Blyth has requested me to add them to his memoir, and have the whole republished in the 'Annals and Magazine of Natural History.' I have acted in accordance with his wishes, and also added references to two species described by Dr. Horsfield, and given the description of what appears to be hitherto an undescribed species, in order to render it as complete a monograph of the Indian species as circumstances would permit.—R. F. T.]

IV.—*On the Mechanism of Aquatic Respiration and on the Structure of the Organs of Breathing in Invertebrate Animals.*

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[With a Plate.]

[Continued from vol. xvi. p. 421.]

Pectinibranchiata.

This order comprehends a considerable number of families and genera. It is the largest and most important group of the Gasteropod Mollusks. In this summary it will be impossible to present a correct analysis, derived from personal observation, of the respiratory organs of every genus. If that were possible indeed to a single observer, an acquisition of great value would accrue to science. The author is deeply persuaded that even in such minute constituents of the organism as a *single* leaflet from the branchial apparatus, the microscope may reveal the presence of differences of shape, size, structure, &c., which may

serve to establish the distinctness of species quite as clearly and convincingly as the grosser characters of the outward appendages. The branchial plates of two separate species, in general position, in form and size, &c., may to the casual eye of the descriptive naturalist, appear absolutely identical. Guided by the microscope, the minute anatomist, however, detects *organic* dissimilarities which enable him at once to assign the objects under view to two distinct animals. A thousand illustrations of this kind may be readily adduced to prove the importance of minute investigations of structure. False analogies suggested by general external resemblances of organs can be authoritatively corrected only by an appeal to the facts of ultimate structure. How utterly confused, how deeply deficient are the views of the comparative physiologists even of these advanced times, as to the history of the renal and urinary systems of the Invertebrate animals! How difficult, in any given instance of doubt, to state whether an organ is a kidney or not! The ultimate elements, those last factors which constitute the essence of the organ, are utterly unknown. For it is not even now determined what is and what is not *essential* to the kidney of an Invertebrate animal. This opprobrium applied but a short time since to the fluid systems and to the respiratory organs. How great are the honours yet in store in this field of research for the clear thinker and fruitful observer!

The general affinities of the Pectinibranchiate order of Mollusks are familiar to all. In all the genera, a spacious branchial chamber exists (Pl. V. figs. 1 & 2). It is a recess over-vaulted by the anterior termination of the mantle. It occupies the last turn of the spire. It is open in front. This arrangement will be afterwards contrasted with the closed character which it exhibits in the Pulmonifera. The Pectinibranchs admit of division into two suborders—the Holostomata and the Siphonostomata. In the former, the margin of the shell and mantle is entire; in the latter, it is either notched or produced into a canal or siphon (*f*). Through this prolongation of the mantle the water enters the chamber. In the Holostomata it penetrates at the same point in the fissure between the dorsum of the animal and the edge of the mantle. The machinery by which the ingress and egress of the water are effected resides in the branchial hood of the mantle. It performs regular respiratory movements. These movements, however, are aided by the invisible agency of cilia. The Pectinibranchs are prosobranchiate. The heart in all affects a position immediately behind the branchial organ. The aërated blood returning from the latter is received directly by the auricle of the former.

What is designated the branchial vault in the Pectinibranchs

is not exclusively a respiratory chamber. It serves to lodge other organs. It contains the heart, the termination of the intestine, the excretory ducts of the reproductive system, and several varieties of glands (Pl. V. figs. 1 & 2). It is therefore by no means an unimportant part of the body of the mollusk. Between the position of the rectum and that of the branchiæ there obtains in this, as in the Pulmonifera, a constant relationship: one reason for this relationship is a mechanical necessity. The egressing current from the gills is thus adapted collaterally to convey away from the body the fæcal excreta. This current connects itself also with the functions of the generative system. It forms a vehicle for the mucus supplied by the glands of this chamber. By its aid the latter is enabled to invest the ova as they escape from the body—constituting thus a cocoon in which they are temporarily cradled. It is by skilfully subordinating the office of one organ to that of another, that Nature's contrivance surpasses man's. In her machinery a force is nowhere allowed to transpire unutilized. It is always deflected to a purpose; though sometimes to one whose significance may prove illegible to her observers.

As the details to which the reader's attention is now solicited are novel, and now for the first time published, it is desirable that a clear and concise method of presenting them should be adopted. The author proposes in the first place to describe the branchiæ in those genera especially of this order in which he has subjected these organs to a special examination. He will then return to a consideration of the glandular apparatus of this important cavity, and finally deduce such inferences with respect to their purpose and function, as their chemistry and the facts of their minute structure may appear to warrant.

The branchiæ of the Pectinibranchs (Pl. V. figs. 1 & 2 *a*' *a*') are almost always fixed to the *roof* of the cavity in which they are lodged. They occupy an intermediate position between the "gland of the mucosity" (fig. 1 *b*) and the colour-gland (fig. 1 *a*, fig. 2 *b*), which lies invariably to the extreme left. In some genera the gill is placed at the extreme left of the chamber—at a point, that is, which is the direct opposite of that of the rectum (fig. 1 *c*). This position is significant of the care with which Nature locates the breathing organ in order that it may receive the most direct influence of the aërating current as the latter enters the cavity. In the following account few differences in the relative anatomy of this organ will demand attention. The most striking diversities will be found to affect the figure or outline-form and ultimate structure of the individual laminæ or pectinations of the gill. These objects are entirely and exclusively microscopic (Pl. V. figs. 3, 4, 9, 13, 14): they are re-

moved in structure far beyond the sphere of naked vision. Since however the individual parts of a pectinibranchiate gill constitute under all circumstances *sheets* whose opposite faces are more or less smooth, or more or less corrugated and folded, a little manipulative skill will be required to enable the student to put to the test of personal observation the particulars comprised in the following description.

The language commonly used by malacologists in describing the gills of this order of Mollusks is calculated to lead to many very false conceptions. They are first said to be "plumes." A 'plume' or feather is *bi*-pectinate, that is, it consists of a stem bearing 'barbs' on either side. Such a word, therefore, conveys to the mind an untrue image of the real object. The word "pectinate" is nearer, but still very erroneous, and very inadequate as an illustrative analogue. A leaf of the gill of a pectinibranchiate mollusk resembles in figure much more nearly a 'fan' than the tooth of a comb. A gill would be a series of fans laid side by side. It should accordingly be defined rather as flabelliform (fig. 4) than pecten-iform. The laminæ of this gill are comparable to a 'fan' moreover in this remarkable particular—they are capable of being closed and opened under the action of muscles. In fact, in other respects they constitute an apparatus immeasurably more beautiful and complex than it has hitherto entered into the dreams of naturalists to conceive.

The branchia (fig. 1 *a, a*) of every genus of this order is seated on a fixed base which forms a part of the roof of the respiratory chamber (*e, e*). In this respect it differs from the breathing organ of the Tectinibranchs, and resembles that of the Cyclobranchs. But the pectinibranchiate gill is distinguished from that of every branchiferous Gasteropod, and is brought near to that of a Lamellibranch by a curious incident of structural mechanism. Each and every leaf of the gill is stiffened and strengthened at one of its free borders by the insertion into its substance of a whalebone-like process of rigid cartilage (fig. 4 *a, a,* & fig. 7). The presence of this process imparts to this edge of the organule a thick straight appearance which stands in obvious opposition to the floating and flexible character of the other margin (fig. 4 *b*). As this process of cartilage is concealed in the substance of the dorsal border of the leaf, and embraced by a dense ciliated membrane, it can only be detected by tearing up the whole leaf into pieces by means of needles. Viewed on its flat surface the lamina presents a triangular outline (*a, b, c, d*). This is more or less the figure of the branchial laminæ throughout the entire Pectinibranchiate group. The terminology applicable in one genus will serve to designate the homologous

parts in all others. That border which lodges the cartilage may be called the dorsal or cartilaginous (fig. 4 *a–f*); that which stretches from the distal point of the cartilage to the extreme end of the base, the free or flexible border (*a, b, g*) formed of the vascular loops; and thirdly, that may be called the fixed side (*c, c*) which is attached to the vault of the cavity throughout its entire extent, and is the mathematical base of the triangle. In some genera a portion of the gill is described as pendent and floating in the cavity. The power to exsert the gill is enjoyed by *Valvata*. It is, however, so exceptional a character, that the branchia in nearly every Pectinibranch may be stated to be sessile on a fixed base. But in describing the gills of this order, systematic naturalists without exception commit another error. In the Siphonostomata, embracing the carnivorous Gasteropods, the "branchial plumes are stated to be double, or to be two in number." In the Holostomata they are said on the contrary to be "single," that is, that there is but one branchial plume. If this error did not originate with, it certainly has been perpetuated by Dr. Sharpey. In his article "Cilia," in the 'Cyclopædia of Anatomy and Physiology,' he states that in reflecting the roof of the branchial chamber in *Buccinum, two sets* of gills are seen, one of which consists of two rows of laminæ (fig. 2 *b*), the other of one row (*a, a*). That structure which Dr. Sharpey describes as a "gill with two rows of laminæ," which is attached to the extreme left of the vault, *is a gland* (fig. 2 *b*; fig. 1 *d*). The details of this point will be given on another occasion. In external characters it looks like a gill. No one but the microscopic anatomist could note a difference. A deep difference however does exist. Here again is exemplified the service which minute special anatomy may render to the cause of general physiology.

His researches enable the author to affirm with confidence, that in all the Pectinibranchiata the gill is a *single organ*. Though in some of the Cyclobranchiata the organ is double, and may exhibit a bilateral symmetry, in the Pectinibranchs it is single. To this rule there is no exception. Since the constituent parts of every pectinibranchiate gill consist of triangular or fan-shaped leaves, strengthened at the dorsal border by a comb's tooth-like process of cartilage, the terms for the construction of an accurate and consistent general definition of the branchiæ in this family of Mollusks are established. A subdivision of these organs into two leading classes becomes essential, however, with a view to a more accurate description of structural minutiæ. In the genera *Buccinum* and *Littorina* the extreme representatives of these two classes occur. The branchial leaf of the former (fig. 4) is distinguished by smooth sides—that is, it is an unpli-

cated lamina having the same minute structure in every part of its extent. In the latter (fig. 3) complex plications (*c*, *c–b*, *b*) occur which multiply to a considerable degree the area of the active surface. This is so remarkable a character, that if the plicæ were a little more prominent, each leaf of the gill of the Periwinkle might be correctly described as a bipinnate structure (fig. 3 B). The plicæ are however mere folds of the smooth surface of the lamina, as will be afterwards explained. These parts are so minute, that the malacologist, using merely the unassisted eye, would pronounce the gill-leaf of *Buccinum* and that of *Littorina* to be one and the same thing,—to be identically organized. But how *essentially* unlike! The evidence furnished by the ultimate anatomy of the *branchiæ* would require that the family of the Littorinidæ should be placed in juxtaposition with the Tectinibranchiata.

The pectinibranchiate gill (fig. 1 *a*, *a*; fig. 2 *a*, *a*) may be defined then as a series of parallel blood-vessels-bearing leaflets, decreasing in size from the centre of the series to either end, projecting at right angles and vertically depending from the walls of the containing chamber. The long axis of the entire organ is parallel with the line of the rectum and that of the glands peculiar to this cavity (fig. 1 *d*, *b*). Though only two main varieties of anatomical structure occur among the branchiæ of this order, the diversities observable in the *size* and *shape* of the laminæ in intermediate examples are as numerous not only as the genera but really as the species. In the genus *Trochus* (figs. 13 & 14) they are more or less similar in all the species. In every species, however, some peculiarity is distinguishable in the contour of the laminæ, which suffices to establish specific independence. Those of *Trochus magus* (fig. 13) are triangular, the dorsal border (*a*, *d*) being slightly convex, the free or flexible border (*b*) being gently concave, while the distal apex is rounded (*a*). The base (*c*) of the longest lamina, which occupies always a position in the centre of the gill, measures about $\frac{1}{10}$th of an inch in full-grown specimens.

In *Trochus cinerarius* (fig. 14), a closely allied species, the distal angle (*a*) is elongated into an acute apex, the free border (*b*) is at first convex and then sweeps into a very prolonged base (*e*, *c*), giving to the attached border twice as great a length as in that of the former species. Other varieties of figure occur in the gill-leaves of *Trochus umbilicatus*, and *T. tumidus* *. The

* In arriving at a knowledge of the exact figure of the branchial laminæ, I have invariably adopted one method of examination. It has consisted in cutting out a few leaves or a small portion of the centre of the gill; the section being coincident with the plane of the laminæ, and at right angles with the long axis of the entire organ. This portion is then carefully

cartilage which occupies the dorsal edge is curved at its point in some species (fig. 12), so that it acquires, its root being the fulcral point, all the resilient qualities of a bow. In others it is blade-shaped (fig. 7). It tends always to straighten itself. This tendency is expended upon the flat surface and the free margin of the laminæ, which are thus maintained in a tightened state, like outstretched or expanded sheets. This is undoubtedly the true purpose which this peculiar cartilage is intended to fulfil in the gills of this order of Mollusks. Its existence has never yet been suspected by anatomists. From the mechanical, lever-like character of its office, it is evident that upon its duly regulated action must depend the function of the entire leaflet. Without it, a sheet of such surpassing delicacy as an individual branchial lamina could not sustain the required vertical position. Without some such contrivance the leaflets would be driven, crushed and folded confusedly by every current and pressure. An elastic apparatus, of inconceivable beauty and perfection, is realized in these hyaline invisible and hidden parts. They hold, with a force of immeasurable gentleness, the respiratory laminæ at such a degree of tenseness as best favours the transit of the water between them, and of the blood throughout the extent of their plane superficies. No crumpling or folding or confusion of any kind can happen even in the relative position of structures of such extreme tenuity and slenderness. And yet it has never occurred to the curiosity of any one of the thousand observers by whom these organs have been witnessed, to catechise Nature as to the mechanism by which such wonders, though minute, are accomplished! In organic workmanship, minuteness and perfection are often twin qualities of the same machinery! These cartilages are peculiar to the gills of the Pectinibranchiata, and as the unfolding of details proceeds, it will be seen that they undergo variations of size and shape, but never of relative position, according to the differences of families, genera, and even of species. Into the branchial system of this large and important order they are special importations, fulfilling purposes of a special nature.

But the office of the border-cartilages is not restricted to the end which has just been defined. They conduct and protect the larger afferent and efferent blood-channels of the laminæ (fig. 3 *e*). It is by thus transmitting a primary column of blood

placed on the glass slip, floated in *salt* water if the specimen be marine in habits, in fresh water if from a freshwater habitat, and then lightly covered with a plate of thin glass. A few laminæ at the same time are detached by means of needles and torn up, in order that the objects may be examined under different points of view. Various reagents are used in the examination of the vessels, cartilages, muscles and fibres, &c. of the organ.

from the fixed border to the apex of the leaflet, that every single spot of the flat surface of the latter is rendered available in the active operation of breathing.

When a single lamina is detached and placed singly, floating in salt water, under the microscope, and viewed as a transparent object, it may be supposed that the spectacle must be one of extreme definedness, every one of whose constituent elements may be readily singled out and read by the eye. This is an *à-priori*, and therefore as usual an erroneous fancy. Nothing is so difficult to the unpractised observer as to read clearly and accurately the spectacle under view. It demands an exercised eye even to distinguish an epithelial particle from a blood-corpuscle, a blood-channel from the crease or fold of the lamina, a near object from one placed at a greater focal distance. Practice and perseverance will however enable the student to interpret with confidence and accuracy all the subtle elements of this inconceivably beautiful structure.

A little experience in the art of viewing the branchial organs of the Gasteropod Mollusks will suffice to assure the least interested observer, that the blood-channels traverse the plane extent of the laminæ in parallel vessels, of uniform diameter, separated from each other by appreciable intervals, and bounded by individual and independent walls (fig. 4 *d, d*). In *Trochus* they appear to run (fig. 13 *e*) from the dorsal edge (*a*) to the free border (*b*) along one face of the leaf, and back again along the other surface, looping round the edge. On both surfaces they are invested in a similar manner by ciliated epithelium, the cilia being large at the edges and small over the flat face of the lamina.

Although the preceding account conveys an exact illustrative image of the type which prevails throughout the branchial system of this multitudinous order, yet as this occasion is the first on which these particulars have been published, it is desirable to enter into an examination of some few other examples of the pectinibranchiate gill.

In *Phasianella* the branchia is said to be partially detached and free in its cavity, but in other relations it imitates the type of the Trochidan organ.

The Paludinidæ are prosobranchiate gasteropod mollusks which inhabit fresh water. It is curious to observe, that this marked contrariety of habitat should occasion no variation of place or structure in the organ of breathing. The branchia of this family, like those of all other Pectinibranchs, affects a position on the vault of the thoracic chamber, having the rectum and generative ducts parallel to it on the right side, and the mucous glands on the other. A siphon exists on the

left of the breathing cavity, while on the right the rectum, as in Lymneadæ, is prolonged in form of a tube beyond the edge of the mantle on the right. In a large specimen of *Paludina vivipara*, it is easy to extract the animal out of its shell by cracking the latter at different points. The position of the organs contained in the branchial vault may be now seen through the mantle. The whole cavity, as in all Pectinibranchs, is ciliated. On the exterior it is also ciliated to a short distance beyond the edge of the mantle. It lies obliquely in the cavity extending from the posterior left corner to the right anterior end. The gill is constructed in exact conformity with the pectinibranchiate model. The leaves of which it is composed are triangular in shape, the base of the triangle being the free border. They rest on a fixed base, and carry a rigid process of cartilage in the substance of the dorsal margin. The blood-channels and the vibratile cilia exhibit the same disposition as those of *Buccinum*, which will be presently explained at length. The heart is situated at the extreme posterior boundary of the cavity near the point at which the rectum joins the branchia. The ovary, filled with young, is seen on the right side of the rectum. The specimen from which the preceding account has been drawn had been for some time preserved in spirit; but the author believes that near the dorsal edge of each branchial lamina in *Paludina, slight traces* of secondary pinnæ, or plications, will be discovered, such as those, far more prominently developed, which are now to be figured and described in the Littorinidæ. If this feature of structure should, on a further examination of fresh examples, be proved to exist, a new point of relationship between the genera *Paludina* and *Littorina* will have been established. In describing their respiratory system, it was once intended to place the Littorinidæ apart as a separate group, in order that contrast of position might attract towards them immediately the attention of malacologists. The author, however, thinks that, for the present—that is, until, by further search, other examples of the same formation shall have been collected,—it is better to place the Littorinidæ here, between the Paludinidæ and Turritellidæ (British Mollusca), rather than dislocate the arrangement of systematists, even at the inconvenience of returning afterwards to the description of the smooth or unplicated variety of branchiæ. A singular abnormity occurs in the gills of the genus *Valvata*. It is protruded for a considerable distance beyond the shell, at the left side of the body of the animal. It consists of a long straight axis, from the opposite sides of which filiform pinnæ or secondary processes project. These again bear minuter pinnulæ, which are the ultimate processes. This gill may be regarded as a transitional variety between the plain,

or smooth, type of the lamina in the Paludinidæ and the plicated form of the organ which prevails probably throughout the Littorinidan family. An opportunity of examining minutely a recent specimen of *Valvata* has not yet occurred to the author.

In the genus *Littorina*, the last turn of the shell is very large relatively to the second and the third. By this criterion, the capacity of the respiratory chamber may be estimated. It presents a considerable size in these mollusks compared with the bulk of the entire body. The augmented dimensions of the cavity are due to the increased volume of the contained organs (fig. 1). The branchia (fig. 1 *a, a*) is highly developed, and occupies a large share of the cavity. It extends from the hindmost boundary to the root of the siphon. It lies obliquely from left to right along the roof of the chamber. Viewed as a whole, it will be observed to consist of two halves (fig. 2 *a, a*), which are divided by a clearly marked line extending from one extreme of the organ to the other. One of these halves (fig. 3 *a, a*) corresponds with the dorsal or cartilaginous borders of the leaves, and consists of a series of parallel unbending rigid lines or filaments; the other half (fig. 3 *g*), more wavy, flocculent, soft and flexible, coincides with the membranous portion of the laminæ. To the left of the gill is situated a peculiar gland (fig. 1 *d*) having a bipectinate appearance, less developed in this mollusk than in *Buccinum*, and which Dr. Sharpey, and after him all systematic malacologists, has described as a *double*, though rudimentary gill. It will be shown that it is a true gland. To the left of the branchia there lies a large glandular mass, which is always enveloped in viscid mucus, and which exhibits a leafy or laminose structure. On the reflected roof (as shown in fig. 1), still further to the left, is observed another glandular mass (*e*), which some anatomists have described as the renal organ; and, lastly, a duct which belongs to the reproductive system (*j*). The structure of these glands will be discussed on another occasion: the branchia only will be at present described. Powdered Lycopodium strewn lightly over the fresh organ will move in one definite direction; namely from the right, or cartilaginous border, to the left, or membranous (arrows, fig. 1 *a, a*). This current, examined more closely, will be found to be subdivided into as many rivulets as there are spaces between the leaves of the entire organ. Of course these superficially indicated currents are but the edges of vertical sheets of water which are in the act of traversing the spaces between the laminæ. These currents are impelled by two forces, one of which is due to the action of the numerous minute muscles fixed to the cartilaginous margins of the laminæ (fig. 14 *c, d*), whose office it is to furl and unfurl, approximate and separate the individual leaves. By this contrivance a mechanical

power is capable of being exerted on the strata of water interposed between the leaves, under which it is driven forwards at a speed regulated by the necessities of the breathing function. The second force is the ciliary. The large cilia which occupy the edges, and which are arranged in rows (fig. 3 *a*, *a*), are capable of raising a sensible current. The minute cilia which are distributed over the flat surfaces of the laminæ drive along only microscopic streams.

By means of a thin sharp scalpel, a section may be easily made through the gill, parallel with the plane of the laminæ, and through the substance of the vault. If this section be made about the middle of the gill, one of the largest laminæ may be readily detached and placed as an individual object under the microscope. Such an object is represented in Pl. V. fig. 3. The dorsal margin curves like a reaping-hook (*a*, *a*). It is stiffened by a large sickle-shaped cartilage (*a*, *e*) which extends from the root to the apex: it supports the whole organ *in situ*. Within this border, running along the side of the cartilage, are also concealed two large vessels, with which many of the ultimate blood-channels of the lamina are connected. Along this dorsal edge are disposed two rows of large cilia, which propel currents in two opposite directions, downwards along one side, and upwards along the other. Every part of the leaf beyond this cartilaginous border consists of a soft membranous substance (*h*), thickly vascular, composed, in fact, of little more than vessels. The next feature to be noticed in the structure of this branchial lamina is a series of duplicatures (*c*, *c* and *b*, *b*) of this surface, and is singularly distinctive of the branchial organ of this family of Mollusks. At first they look like accidental folds of a delicate membrane; but as they occur in every single leaf throughout the organ, it follows that they are organic formations. If the leaflet is laid carefully on the glass slip, floating in water, and gently covered, *without pressure*, the true character of these parts may be most clearly determined. They consist undoubtedly of a *bifid* fold (B) of only one half of the lamina, for a similar fold exists on the opposite surface. Each fold is made up of two parts, which are united gradually at either end, and separated by an interval in the middle. The long axis of each fold is at right angles with the line of the dorsal margin; but the row is parallel with the latter. Slightly beyond this row of plicæ, and nearer to the centre of the leaflet, is to be observed a second and smaller system (*c*, *c*). The folds are formed in the latter case precisely as in the former. These two systems of plications are separated from each other by a narrow space of smooth membrane. All that portion of the lamina which intervenes between the second row of folds and the extreme apex (*j*) of the lamina is a plain unplicated surface,

sustaining a double series of parallel blood-channels. The anatomy of the folded portion of the leaf may be better understood on a tranverse section (such section is represented at fig. B). It will be seen that the duplications of the surface are the same on both sides (*f*,*f*), and that the opposite folds are formed upon the same transverse axis.

The next problem to be solved in the analysis of this most beautiful mechanism relates to the disposition of the blood-vessels (*h*, *h*). This question could never be determined by injections, however fine or successful. The practised eye, reading the same structure throughout an extended series of varieties and modifications, may infallibly decipher the blood-system even of these subtle and delicate laminæ. The leaf tapers away into a slender point at the extreme membranous end (*j*). If the same blood-channel, or the same drop of blood, travelled from the dorsal border (*a*, *a*) across the entire length of the laminæ, as far as the tapering point (*j*), it is evident that such a portion of blood would undergo an excessive degree of aëration, while that which traversed the space at either apex (*i*, *h*) would fall short of the required amount of oxygenation. This inconvenience is obviated by giving to the vessels a *generally* oblique direction across the plane of the lamina (*d*, *b*). The vessels as they traverse the folds (*c*, *c* and *b*, *b*) maintain the same character and direction as they exhibit on the smooth portions. This fact proves that these folds are really none other than duplications of the surface. They serve, notwithstanding, to multiply the active superficies of the little organ, and the vessels which they carry, although unaltered in direction, are smaller in diameter and more closely arranged. The ciliary action over these portions is also more active and vigorous than on other parts. The vessels are most distinct in outline and disposition about the central region of the leaf (*h*, *h*, fig. 4 *d*). That the channels are conduits, distinct and individualized, separately walled, running side by side, and seldom inosculating, may be unquestionably proved by the steady examination of this part. That the channels loop around the free edge (figs. 5 & 6) to gain the other side, along which they return, the observer may convince himself by focusing the microscope at this border. The appearance is then such as is shown in fig. 5, and fig. 9 *b*. The cilia of the flat surface are seated on a pavement epithelium, those of the borders stand out like filaments from a larger description of cell (fig. 8).

The author has proved, that in all the species of the genus *Littorina* discoverable on the coast around Swansea, the branchial laminæ are constructed on the model (fig. 3) of that just described. The duplications are not of the same precise size and character in all; but in all they exist. He would propose this

incident of structural type as a criterion of relationship between the several genera of the family of the Littorinidæ. He has not examined the branchiæ of *Lacuna, Assiminia, Jeffreysia* and *Skenea*; but those of the genus *Rissoa* discover a marked tendency towards this peculiarity of formation.

Several families must now be passed over as hitherto unexamined. The branchiæ of the Muricidæ may probably, however, be considered as typically representative of those groups which intervene between them and the Littorinidæ.

The whole of this extensive family is said by systematic authors to be characterized by the possession of *two gills*; one described as doubly pectinated, and the other as singly pectinated. As formerly stated, Dr. Sharpey has adopted this definition in his article "Cilia," in the 'Cyclopædia of Anatomy and Physiology.' The branchial chamber in this family (fig. 2) is constructed on the same principle as that of other Pectinibranchs. It is a capacious vault, open in front from one side to the other by a fissure. On the left side the edge of the mantle is prolonged into an extended recurved siphon. The glands (*c, b*) of the cavity, as will be explained afterwards, are highly developed; one of them so much so as to have led to the idea that it was a second branchia. The true gill (*a, a*), which is a single organ, stands between this supposed supplementary gill and the large mucous gland (*c*), to the left of which is observed the rectum (*e*). In the Muricidæ, the third gland (fig. 1 *g*), called by some authors the renal gland, is not visible within the boundary of this cavity. The whole of the interior of the chamber is actively ciliated; the exterior is *not* so. The epithelium here is smooth. Little peculiarity exists in the branchial system of this family (fig. 4). The organ is large (fig. 2 *a, a*); it has the shape of two cones laid base to base. The broadest laminæ are therefore in the middle, the smallest at either end. It is so situated as to receive directly the column of water as it enters by the siphon (*f*). The course of this water, as indicated by the arrows (fig. 1), is from left to right; it thus passes first, and in the most pure state, over the branchiæ, then over the mucous gland, and lastly over the rectum. The planes of the branchial laminæ (fig. 4) are coincident in direction with the main water-current in passing from the left to the right side of the branchial cavity. Nothing is so easy as to determine the figure of the gill-leaves in any of the larger genera of this family. *Buccinum* is a familiar example.

The gill of *Buccinum undatum* is composed of many hundreds of leaves. These leaves, towards the centre of the organ, are regularly triangular in figure (fig. 4 *a, a*). At the extremities, each lamina loses more rapidly in vertical depth than in length, so that at last they become scarcely visible creases of the pallial mem-

brane. The membranous border is drawn out to a considerable length (*g*) beyond that part of the gill which is apparent to the naked eye. By this extension of the active branchial surface, the action of the aërating current on the blood is prolonged. In no single instance of the pectinibranchiate gill are the cartilages of the laminæ so developed as in this family. It is here that the true structure and office of these singular elements of the branchial mechanism may be most advantageously studied. In the branchia of *Buccinum* they are straight, sword-shaped blades (fig. 7); they are skilfully fitted into the dorsal or thick edge of the lamina (fig. 4 *a, f*); they act the part of beams, or arms, whereon is hung the sheet of the leaflet (*a, g*). Without them, the latter could not by any means be held *in situ*; that is, could not be maintained at that degree of expansion essential to the proper and adequate contact of the blood with the water. To the bases of these cartilaginous beams, muscles (fig. 14 *c, d*) are attached, which are capable of influencing the entire leaf. Under their action it may be either stretched lightly or folded together like a closed fan. The flat surface of the branchial lamina in *Buccinum* is always unplicated.

In the fresh specimen it may be seen, with perfect clearness, that it is traversed by waving parallel blood-channels (fig. 4 *d, d*). In no instance among the Pectinibranchs is it more easy to convince oneself that these vessels loop at the free flexible margin (*c*) of the leaf than in *Buccinum* (fig. 5). The laminæ are considerable in superficial area (*a, g*), exhibiting a surface equalling a tenth of a square inch. The vessels (*d*) are prominent, being readily traced by $\frac{1}{2}$ an inch power. The walls display a granulated character (fig. 5 *g, g*), in consequence of the contents of the epithelium. This circumstance individualizes each blood-channel most clearly. The flat surface of the leaf is also covered by a flat, scaly, polygonal epithelium (fig. 6), the cells of which are filled with minute granules, and armed with short cilia. Along the base or fixed border of each leaf run two large vessels (fig. 4 *c, c*), one of which is afferent, the other is efferent. Thus, in brief, is written the anatomical history of this remarkable organ. It is at once evident that the key-stone of this structure is the beam of cartilage, which imparts strength and rigidity to the dorsal margin of the slender sheet; and, further, constitutes a point of attachment to a system of muscles, by which, as by a lever, the entire apparatus may be extraordinarily furled and unfurled, and otherwise variously controlled.

Another example of the Muricidan gill may be described, in order to show, that in two closely allied species of the same genus a striking difference of structure may occur in one and the same organ.

The *apices* of the laminæ in the gill in *Purpura lapillus* are

curved sharply (fig. 9 *a*). In *Buccinum*, as just stated, the dorsal border terminates in a straight point. Although this trait is only a microscopic incident of formation, it is quite enough to constitute the distinctness of the species. In every other respect the laminæ discover the same structure as that just explained in *Buccinum*. The gill-leaves of *Murex* and *Nassa* exhibit also slight variations of *shape*, compared with the standard figure of those of *Buccinum*. From such examples the naturalist may well exclaim, how marvellous and unaccountable, that in establishing the independence of species, Nature should change the very fabric of the minutest parts of the body!

In the Conidæ and Cypræadæ, the author has every reason to believe that the branchiæ conform with exactness to the type of those of *Buccinum*. They may vary in the special outline of the laminæ, but not in essential structure. They lie in the branchial chamber in the same oblique position, and exhibit the same relation to the glands of the cavity.

Although the transition may be strange and abrupt, it is convenient at this point to pass to the consideration of the pulmoniferous Gasteropods; not because there is much in common between their breathing system and that of the branchiferous orders, but because the glands contained in the thoracic cavity of the Pulmonata correspond in structure and dependencies most intimately with those which are contained in the branchial chamber of the Pectinibranchs last described. According to this distribution of subject, the "glands" of the respiratory cavity of both the branchiferous and pulmoniferous orders will come to be considered under one head.

[To be continued.]

V.—*On the Origin of the Geographical Distribution of Crustacea.* By Mr. James D. Dana.

[The present paper is the conclusion of Mr. Dana's Report on the Geographical Distribution of the Crustacea. As the opinions here put forward appear to be of great importance in the study of the geographical distribution of animals, we have thought it advisable to transfer this portion of Mr. Dana's work to our pages; but the tables of facts on which they are founded would occupy too much space; they will be found in Silliman's Journal, vols. xvi. xviii. xix. & xx. —Eds.]

The origin of the existing distribution of species in this department of zoology deserves attentive consideration. Two great causes are admitted by all, and the important question is, how far the influence of each has extended. The first is, *original local creations*; the second, *migration*.

Under the first head, we may refer much that we have already